

Use of a Terminal System for Data Acquisition

Abstract: The application of a mathematically-oriented conversational computing system to data collection and computer control for a specific experiment is described. Relatively simple interfaces are used between the experiment and computer terminal to provide for voltage analog inputs and outputs to the experiment. The terminal is connected to the computer by way of conventional voice-grade telephone lines. It is concluded that this type of data acquisition system is quite useful for experiments in which several-second computer response time can be tolerated, data reduction is necessary and the computer load is insufficient to justify the use of a local computer. An additional facility which provides for the ability to plot data was found to be extremely useful.

Introduction

The purpose of this paper is to discuss the application of an existing mathematically oriented conversational computing system (APL/360) to both the acquisition of data and the control of associated equipment. In the particular experiment for which this was done, three different types of measurements were being performed on light-emitting diodes (semiconductor diodes which emit optical radiation when a forward current is passed through them). Such a large number of light emitting diodes (LED's) were being evaluated, as a function of several fabrication parameters, that computerized data acquisition and control were used to avoid the tedious and time-consuming task of taking all of the necessary data by hand and then typing it into the computer for analysis and curve fitting.

Computer control of experiments with associated on-line reduction of resulting data is widely used at present and its uses are continually expanding. Such applications, however, generally use small computers dedicated solely to the experiment in question or somewhat larger machines, designed primarily for this type of use, which are time-shared between several pieces of equipment.^{1,2} In the present experiment, the percentage of the working day in which the measurements were conducted did not justify the use of a computer dedicated solely to this job and no computers of the second type mentioned above were readily available. Thus it was decided to connect the experiment to a large problem-solving oriented computer for which a terminal, connected over regular voice-grade telephone lines, was already available in the laboratory. The use of such systems for data acquisition is relatively recent³

and experiment control has generally not been provided. The results of the use of such a system and its limitations will be discussed following a description of the measurements to be performed and the manner in which they were implemented.

Summary of measurements performed

The primary use of the system is to automatically digitize the waveform on a sampling oscilloscope and enter it into a time-sharing computer. This is done to analyze the rise time of the light emission from the LED's, which may vary from several nanoseconds to several microseconds. The system is designed so that the sampling oscilloscope, which displays the output of a photomultiplier versus time as a series of discrete points, can have its beam positioned horizontally by the computer. The computer can then interrogate the measuring apparatus to determine the corresponding vertical signal. Provision is also made to keep running track of the data being taken, with various normalization and correction factors applied, on a plotting device attached to the system. This allows the operator to be sure all is going well or to abort the run should something appear to be wrong with the data. The additional time added to the run by this plotting is insignificant.

An addition was later made to the system to automatically perform the second phase of the experiment: measurements of steady-state light output and voltage drop as a function of diode current. The current at which a given reading is to be made is set by the computer and then the resulting data are directly entered into the computer for reduction and tabulation at the completion of the test. The only operations which the operator must

The author is located at the IBM Watson Research Center, Yorktown Heights, New York.

Table 1 Operations performed when ← is in Register 1 and indicated character is in Register 2

Register 2	Operation performed
A	Load DAC #1 from registers 3, 4, 5.
B	Same as "A" plus delay trigger for DVM
C	Load DAC #1 from registers 3 & 4 Load DAC #2 from registers 5 & 6 After delay, unblank storage tube
D	Load DAC #2 from registers 3, 4, 5 and give trigger
E	Load DAC #2 from registers 3, 4, 5
F	Reset flip-flop
G	Switch state of flip-flop
H	Give contact closure
I	Give contact closure

perform for this measurement are the mounting of the LED in the test fixture and entry of diode identification and current limits via the terminal keyboard.

The same time-sharing computer-system is used in the third phase of the experiment to store life-test data (light output as a function of operating time) originally taken on punched cards in a separate semi-automated measuring system and present the latest data in a usable form.

General description of system

The basic components of the time-sharing computer used are an IBM 360/50 computer to which is connected an IBM 1050 terminal via phone lines and Western Electric 103-A Data Sets. To this have been added two specially designed interface circuits, a sampling oscilloscope, a digital voltmeter (DVM), two digital-to-analog converters (DAC) and a programmable power supply with a small amount of logic circuitry added.

The input interface was designed by L. B. Kreighbaum of the IBM Research Center and has been used in some data acquisition experiments in which no computer control was desired.³ It is designed to take information from a DVM and, through proper coding and sequencing, to enter the readings into the 1050 terminal. The interface is connected to one of the Reader inputs of the 1050 and as far as the terminal is concerned completely simulates a reader.

The output interface was specifically designed for the experiments being discussed to provide various control functions which are derived from computer commands. This circuit simulates a Punch by receiving BCD data from the terminal and in turn supplying appropriate interlocking signals through the Punch connection. Since APL/360 presently does not have the capability of selectively addressing individual output components of the 1050 terminal, all information coming into the terminal is transmitted to the output interface. In the interface the

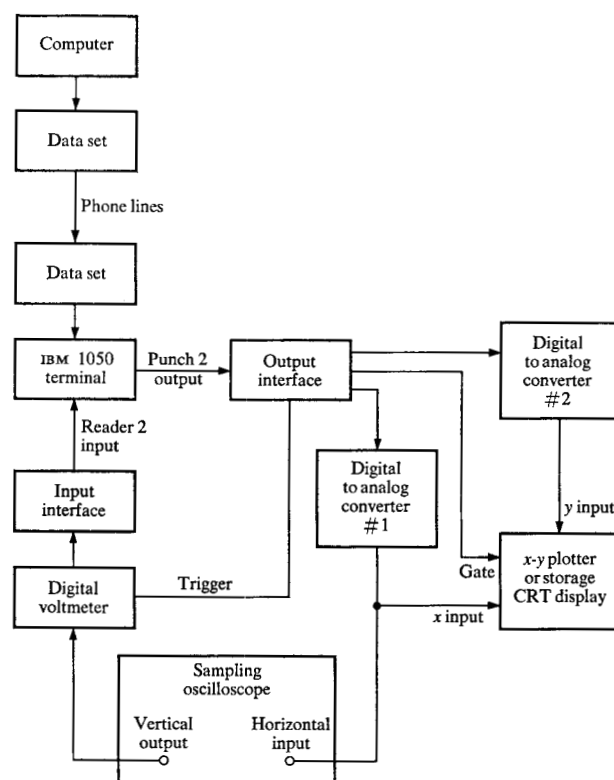
information is passed through a six position shift register with no further action taking place unless the symbol is detected in register one. This indicates that registers 3 through 6 now contain digits to be used in some operation and register 2 contains an alphabetic character indicating how the digits are to be used. Table 1 indicates the various command options that have been incorporated in the interface. Commands A through E are used to control the oscilloscope and plotter deflections and can be used in general for any application requiring an analog signal. The remaining commands are used to operate the penlift on the x-y plotter, to initiate operation of the Light-Voltage-Current measurement apparatus and to perform miscellaneous other control functions. Thus the interface could be applied to other experiments because of its ability to provide a wide variety of control functions from very simple computer commands.

Specific system application

• Oscilloscope data acquisition

A block diagram of the oscilloscope data acquisition system and plotting apparatus is shown in Fig. 1. When the amplitude of a particular point on the oscilloscope

Figure 1 Block diagram of sampling oscilloscope and plotter control system.



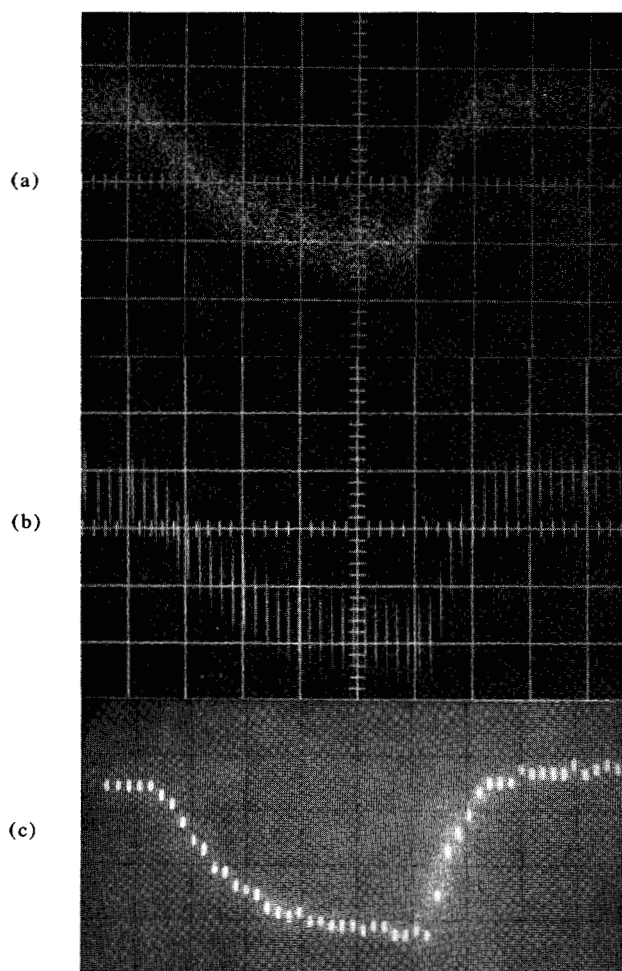


Figure 2 Comparison of "noisy" waveform on sampling oscilloscope with same data taken plotted by system. (a) Conventional sampling oscilloscope presentation of waveform, (b) Photograph from sampling oscilloscope taken during data taking operation, (c) Data after being automatically taken and displayed on storage oscilloscope (intentionally defocused to make points stand out better).

waveform is desired, the computer transmits the decimal value of the voltage that corresponds to the horizontal coordinate of the point in question, together with two control characters. This information is received by the terminal and in turn transmitted to the output interface. After decoding the control characters, this interface circuitry loads the numbers received into a DAC whose output controls the horizontal position of the oscilloscope beam. Thus the beam is now located at the desired point on the waveform. After a suitable delay to allow transients to die out, the interface transmits a trigger to the DVM (connected to the vertical output of the oscilloscope) which causes it to start taking a reading. When the DVM is finished integrating, normally one second, its output (which consists of 6 digits, sign and decimal location)

is transmitted to the computer by way of the input interface.

The speed of the system in this mode of operation is rather slow by normal computing standards because the computer connection is through a terminal which operates at 14.8 characters per second and the line must be turned around (i.e., direction of transmission changed) between each set of control characters and the corresponding reading. Five control characters are sent and 8 characters returned (6 digits, sign and decimal location) for each point, thus giving a transmission time of about 1 second. Line turn-around is nominally one-half second so this adds another second per reading. In addition there is the integration time of the DVM (1 second at present) and some delay in the computer processing dependent upon the number of users of the central computer. Thus the time per point is somewhat over 3 seconds and several minutes are required to enter a reasonable number of points for a curve.

The 1-second integrating time used on the DVM gives very good rejection of noise that may be added to the signal. This rejection is greater than 40 db for frequencies above 50 cycles. Figure 2 shows a "noisy" curve photographed on the sampling oscilloscope and the same data after being taken with the system and plotted on a storage scope.

Provision has also been made to allow local automatic sequential scanning of the horizontal axis of the oscilloscope without computer control by using local stepping switches. This arrangement permits the system to operate somewhat faster than when under computer control, by eliminating the time in which control information would be sent by the computer as well as the turn-around time of the phone lines (a total of more than one second per point). Considerably more flexibility in the order of scanning, the density of points on various portions of the waveform, and the timing between readings can, of course, be obtained when the system is under computer control. Such control also provides the ability to retake readings which seem to be in error upon analysis of the data. A combination of the two systems can also be utilized, in which the waveform is first scanned locally and then the computer is given control to go back and retake points or fill in data where desired.

• *Light-current-voltage data acquisition*

For the second phase of the experiment (acquisition of light-current-voltage data) the additional apparatus outlined in Fig. 3 is connected between the output interface and DVM of the original system. The interface transmits two digits plus a trigger to this additional logic circuitry. The first digit causes one of eight possible resistors to be connected to the control input of the programmable power supply. This selects one of eight output voltages covering

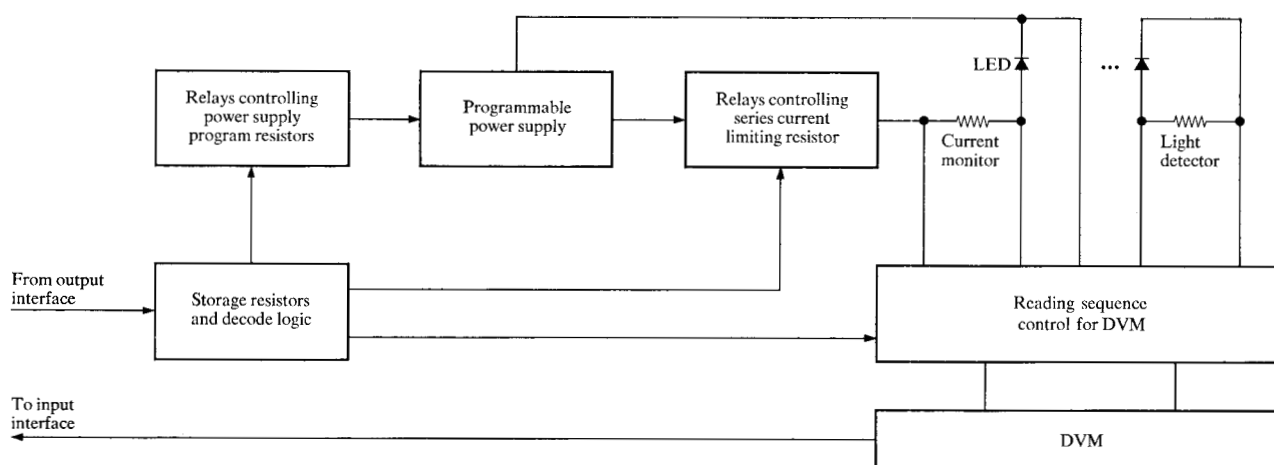


Figure 3 Additional test apparatus for steady-state light-current-voltage measurements. (Lines with arrows indicate logic circuits as opposed to measuring circuits.)

a range of a decade. The second digit determines which of four resistors are connected in series with the diode under test and thus which particular current decade is selected. After an appropriate settling delay, readings are sequentially taken of light output (solar cell voltage), diode voltage, and current (as indicated by the voltage drop across a standard resistor). Control is then returned to the computer to select the next point.

◆ Life-test data acquisition

Life test data are taken in a semi-automated system constructed several years prior to the availability of APL/360 or any appropriate terminal oriented system. To use this apparatus, the operator must connect two 33-contact plugs to a desired test panel and push a button actuating the equipment. Readings of light output, diode voltage drop and diode current are then taken sequentially on the 20 test diodes on the panel and put on punched cards using a special interface and an IBM 526 Card Punch. Appropriate identification data are also punched. The data must then be entered into the APL/360 system by reading the cards on a reader attached to the terminal.

◆ Plotting mode of operation

Data can be plotted on a storage CRT or an x-y plotter by using essentially the same system as that described for oscilloscope control. The only additions are a second DAC and the desired output device, as shown in Fig. 1. For this operation the control characters decoded by the output interface tell it to load a certain portion of the received data into each DAC and then either unblank the beam of the CRT or momentarily drop the pen of the x-y recorder.

The resolution of the 5" storage CRT used is approximately 100 line pairs in each direction and thus it is worth-

while to transmit only two digits for each coordinate. These, together with the two control characters for the output interface, give a total of six characters which must be transmitted for each point to be plotted and thus data can be plotted slightly faster than two points per second. If a mechanical x-y plotter is used, operation will be somewhat slower because a delay must be inserted between the loading of the DACs (simultaneously loaded with 2 digits each or sequentially with 3 digits each for greater accuracy) and the transmission of the "pendown" command to allow for the slewing speed of the plotter. In general about 1 point per second can be plotted if extreme plotter excursions between points are not encountered.

Comments on use of system

◆ Programming

The programming for all operations is very simple with the system used. It makes use of APL/360, which is an interpreter based on the Iverson Language.^{4,5} Because of the experimental nature of this project, the use of an interpretive language was thought to be particularly advantageous since the programs would not have to be recompiled each time a change was made. This quality of APL/360, its similarity to ordinary mathematical expressions, and its inclusion of powerful primitives were the primary reasons for its choice in this application.

As mentioned previously, the computer need transmit only 2 interface control characters plus up to 4 digits of information to execute any of the rather versatile operations indicated in Table 1. This can be done in one line of an APL/360 program since literals (the control characters) and a numeric variable can be catenated in output operations. The symbol was chosen as the primary interface control character since it is normally generated by the

computer only in program listing operations and thus would not inadvertently be produced during an experiment. Any resultant information or data displayed on the printer during a run will have no effect on the control functions.

Input of data to a program is accomplished through the use of the quad ($\square$) operator in a statement. For example, if the execution of a program proceeded to the point where it encountered the statement:

DATA $\leftarrow$ $\square$

the terminal would then be polled for some input. If the DVM has been previously triggered, the input interface will transmit the resultant data, providing of course that it is switched on-line. The format of data and the number of readings that will be entered and assigned to this variable are determined by a plug-board in this interface. After the desired amount of data is transmitted, an end of block signal is sent and the program resumes operation. If the DVM has not been triggered by some control information prior to the "read" statement, the operator can enter data, descriptive information, program branching information, etc. from the keyboard at this time.

Thus the I/O operations can be programmed as quickly as the data manipulating operations with this easy to use language. The lack of the need for compilation permits the operator to stop program execution at any time, modify some desired statement and then continue operation under the modification. Also, the operator can easily perform further data manipulations and display the results after seeing the preliminary data. This can be done either by invoking existing programs at this time or by operating on the data directly.

• *Oscilloscope control mode*

The system has been primarily used in a study of the speed of response of light emitting diodes, although it can of course be used for entering any data from a sampling oscilloscope into the computer. In the present study, an attempt is being made to find a suitably general mathematical expression which will fit the shape of the light output versus time curve obtained when LED's fabricated in various ways and tested under various environments are driven with a step input of current. An understanding of the detailed variation of the parameters, in this expression, with device and test properties lends additional insight into the factors controlling the speed over that found from the more easily and conventionally obtained 10 to 90% risetime figures (or time constant). Such evaluation of parameters cannot, of course, be done by simple measurements on the waveform as presented on the screen of the oscilloscope if the waveform is to be represented by more than a simple exponential. Even in that simple (single exponential) case it is not always easy to determine a single time constant accurately, because of noise. Also, no simple measurement

has been found which can be performed on the waveform as displayed to determine with sufficient accuracy whether it can be represented by a single exponential. For these reasons, the waveforms were digitized and various computer analyses performed on them.

Although the speed of response of the system tends to seem quite slow to an operator, it is considerably faster and more accurate than could be done by hand. It should be mentioned, however, that if the nature of some other experiment is such that low frequency drift is to be encountered, the slow operation of this system might make its use unacceptable. In such a case it may be more appropriate to have a local computer dedicated to the experiment so that the data can be taken more rapidly.

Voltage waveforms examined in experiments of this type frequently tend to be quite noisy. This is due to noise generated in the photomultiplier when operated at low light levels, susceptibility of the circuitry to power line frequency pick-up because of the low signal levels, etc. The use of the integrating technique gave excellent noise rejection and permitted much more information to be extracted than could be done by visual observation.

• *Steady-state light-current-voltage data acquisition mode*

Light output and diode voltage drop are measured at about 30 to 40 different values of diode current for all LED's put on life test, most of those on which speed measurements are made, and various others. This amounts to a total of about 500 diodes per year on which these data must be taken. In most cases the measurements are repeated at the completion of a test and compared with the initial data to determine what changes have occurred in the device characteristics; consequently this doubles the readings to nearly 1000 per year. These comparisons are presently being done using computer plots on the storage CRT with the time-sharing system, as compared to the previous slow hand plotting. In many cases it is desirable to also know numerically the slope of light-voltage and current-voltage curves at several selected points as well as to make visual comparisons. Also, an analysis is frequently performed on the data to determine the series resistance of the devices. Thus it is practical to have the data directly entered into a computer rather than taking them by hand and in turn typing them into the terminal.

The automated system has two distinct advantages over the manual technique, viz., accuracy and speed. When a group of diodes is being tested, and consequently over 100 readings per diode must be entered into a notebook and then later typed into the computer, it is quite easy to make some errors which are much less likely with the automated system. Although the speed improvement in the data acquisition part of the test alone is not outstanding, it is very great when one considers the entire operation of taking and recording the data, entering them into the

computer and plotting the results. Furthermore, the control capability of the computer permits such functions as termination of the test if the trend of the data indicates that a diode may be damaged by using the originally specified current limits. Another very useful function of computer control would be to maintain optimum signal output from the optical detector by appropriately changing its load resistance as conditions change. A sample output is shown in Fig. 4.

• Life-test experiments

At any one time over 400 LED's are on life-test to determine how the light output and electrical characteristics vary as functions of time. Data are periodically taken (every 24 to several hundred hours, depending upon how far the test has progressed) on a semi-automatic system which punches the resulting data onto cards. These cards are then read into the computer terminal. A number of programs have been written to present the data on particular devices in the manner most useful for the property being investigated. This analysis using the time-sharing system is much more convenient than the previous method in which the data had to be analyzed by programs under a batch mode of operation with its inherently much longer turnaround (an hour as compared to about a minute at present). Also, with the ready availability of the data one tends to make much better use of them, for example by conveniently obtaining correlations between the many test parameters and results. The only disadvantage with this system is the slow card reading speed of a terminal oriented system (6 cards/minute with the present system). However, these can be read unattended at a time when the terminal is not being used.

Conclusions

Through two special interface circuits connected to an IBM 1050 terminal several experiments have been run on-line with programming by an interpretive language on an IBM 360/50 computer. The system provides a reasonable degree of control of the experiment as well as satisfactory data acquisition and plotting facilities.

Although the operating speed in some cases is quite a bit slower than could be obtained with a local computer connected directly to the experiment in question, the speed is generally adequate for this type of experiment, and certainly faster than conventional hand operation, and the accuracy is much greater. In the plotting mode of operation the speed was far superior and the resolution somewhat better than the conventional terminal technique of "plotting" with the typewriter.

The interfaces used are sufficiently versatile in their operation that the system can be used for a wide variety of measurements where the speed of operation is consistent with experimental requirements. The input interface

DIODE 44-13-68 JULY 2, 1968				
N CALCULATED FROM FIRST 8 POINTS OF RAW I-V DATA IS: 1.81				
N CALCULATED FROM FIRST 8 POINTS OF COMPRESSED L-V DATA IS: 1.04				
DIODE CURRENT	CORRECTED VOLTAGE	SERIES RESISTANCE	UNCORRECTED EFFICIENCY	N FOR I-V (CORRECTED)
0.04	1.329	0	0.05	0
0.06	1.339	0	0.05	0
0.08	1.353	0	0.062	0
0.1	1.368	0	0.09	0
0.2	1.396	0	0.135	0
0.3	1.414	3.138	0.179	1.635
0.5	1.435	4.84	0.25	1.759
0.7	1.448	4.454	0.299	1.723
1	1.461	6.019	0.349	1.589
2	1.486	8.119	0.46	1.532
3	1.5	9.016	0.533	1.471
5	1.517	9.618	0.619	1.394
7	1.528	9.631	0.671	1.349
10	1.539	9.713	0.73	1.319
15	1.552	9.787	0.786	1.266
20	1.56	9.826	0.815	1.223
30	1.571	9.368	0.849	1.176
40	1.579	9.217	0.849	1.135
50	1.584	8.825	0.839	1.087

Figure 4 Sample output from steady-state light-voltage-current measurement. N is the constant in the expression $\exp(QV/Nkt)$ when the dependence of light or current upon voltage is assumed to be exponential. A zero entry indicates no calculation of parameter for that point.

requires only that the instrument supplying data to it have a BCD output and that it hold its reading until the information has been entered into the computer. The output interface can provide up to four BCD digits, analog outputs and various types of contact closures for control operations. No modifications are required on the 1050 terminal except that it be equipped with the required features for the attachment of a punch and reader.

It is concluded that data acquisition and experiment control by use of voice-grade line connection to a conversational computer system is very useful for the class of experiment discussed. Specifically these are experiments where the nature is such that several-second computer response is not detrimental, significant data reduction is necessary and the load is too light to justify the use of a local dedicated computer. In addition to simplifying data collection, this particular system permits the operator to have all the facilities of a large mathematically oriented computer available for his subsequent data reduction operations through the use of a simple but powerful language. For pure data collection where no data reduction is to be done the time savings may be questionable although the accuracy is probably much better (but not necessarily sufficiently so to warrant the use of this type of system.)

Acknowledgments

I would like to acknowledge the many helpful discussions with J. B. Davis on the logical design of the output interface, the construction of this interface by J. C. Topalian and the design of the input interface by L. B. Kreighbaum together with his helpful comments on its use.

References

1. Jack W. Frazer, "Instruments and Computers," *Science and Technology*, No. 79, 41 (July 1968).
2. G. Lauer and R. A. Osteryoung, "A General Purpose Laboratory Data Acquisition and Control System," *Analytical Chemistry* **40**, No. 10, 30A (Aug. 1968).
3. H. A. Reich, "An Experimental System for Time-Shared, On-line Data Acquisition," *IBM J. Res. Develop.* **13**, 114 (1969), this issue.
4. Iverson, K. E., *A Programming Language*, Wiley, New York, 1962.
5. L. M. Breed, and R. H. Lathwell, "The Implementation of APL/360," *ACM Symposium on Experimental Systems for Applied Mathematics*, Academic Press, 1968.

Received July 12, 1968.